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THE UNIVERSITY OF MICHIGAN
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High Altitude Engineering Laboratory
Departments of
Aerospace Engineering
Meteorology and Oceanography

Final Report

REDUCTION AND ANALYSIS OF DATA FROM OGO-IV EXPERIMENT 15

R. J. Leite, C. J. Mason, and J. Spencer

ORA Project 033460
under contract with:
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GRANT NO. NGR 23-005-383
WASHINGTON, D. C.

administered through
OFFICE OF RESEARCH ADMINISTRATION ANN ARBOR
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Abstract

This is a final report submitted in fulfillment of requirements of NASA Grant No. NGR 23-005-383 for continuation of data processing for OGO-IV Experiment 15. Funding limitations made use of the University Computing Center facilities impractical for processing these mass spectrometer data. Manual techniques were attempted but proved to be unreliable due to the sharpness of the spectral peaks and the fact that the data were commutated. A data processing program for a Digital Equipment Corporation PDP-8 computer was formulated and tested. This program appears to process these data satisfactorily. Recommendations for continuation of the data processing are included.

I. Introduction

This report is a summary of work performed between November 1, 1969 and November 30, 1970 on NASA Grant NGR 23-005-383 entitled "Continuation of Reduction and Analysis of Data From OGO IV Experiment 15." It describes the procedures used to process the atmospheric composition data obtained through the use of a sweeping quadrupole mass spectrometer on OGO-IV. These data were stored in digital form on magnetic tape. Attitude-Orbital data were provided in digital form on magnetic tape also. These two sets of data are correlated in time through date-time comparison. A discussion of conclusions concerning reduction of commutated spectral data and the difficulties associated with interpretation of these data are included. It is shown that use of an electronic computer of appropriate capacity provides the only realistic approach to the processing of commutated spectral data.

A computer program was developed to 1) extract the spectral data from magnetic tape, 2) apply instrument calibration factors, and 3) adjust the mass concentrations for the velocity of the spacecraft, the angle of attack of the sensor, and the influence of the spacecraft upon the local distribution of constituents. The computer output is a listing of the ambient concentration of each detected constituent, altitude, geographic location, date and time of the measurement.

II. Approach to data processing

The task of reducing commutated spectral data in such a manner that reliable, reproducible results are obtained, is not only tedious but also very complex. In the case of Experiment 15 on OGO-IV, it was necessary to explore thoroughly every detail of the spectrometer, the data handling system, and the characteristics of the observatory in order to develop a technique for proper processing of these data. We made some false starts and pursued a number of unproductive approaches, however each of these provided us with better insight into the overall problem and singled-out trouble areas requiring additional investigation.

Previous attempts to use computer methods to process the mass spectral data from Experiment 15 on OGO-IV have provided only limited results. Due to the continuous upgrading of the University Computing Center facilities to higher generation machines, the cost of rewriting and trouble shooting the software, the increased costs of the more sophisticated computers, and the inavalibility of data processing funds to keep pace with data processing costs, it became impossible to use the facilities. An equally debilitiating problem, however, was the fact that the University Computing Center was never intended to be a data processing facility.

In view of the extremely limited budget and the above considerations work on the present grant was directed toward utilizing and improving manual techniques to extract the composition data from strip charts and print-outs derived from the Experiment Data (E/D) and Attitude-Orbit (A/O) magnetic tapes, respectively. Studies of four specific areas of interest were to be undertaken using the above procedures.

At first, the manual approach appeared to be satisfactory in spite of the relatively lengthy time required, however, due to the fact that these data were commutated, visual determination of the actual vertex of a spectral peak is not generally possible without the use of a model which is fitted to the commutated data points. Manual fitting of the model to overlapping peaks is not feasible, even if only minimum accuracy were required. In general, model fitting requires precision beyond that possible using manual and visual methods, hence, any hope of reliably and consistently extracting any data from the commutated spectra appeared to be extremely remote. Therefore, all manual data processing was abandoned and a search for another approach was initiated. It was apparent that unless some inexpensive computer processing approach could be found, processing of the Experiment 15 mass spectra data would have to be abandoned completely.

After careful evaluation of what was known about the experiment, the data, the spacecraft, and the data handling system, together with an examination of the capacity the PDP-8 computer included in our data acquisition system, it was concluded that data processing would be possible if multiple passes through the computer were acceptable. The limited amount of memory storage and peripheral equipment are the controlling factors.

Utilizing the softwave previously developed for use at the University Computing Center as a guide, work was initiated to compact the program as much as possible by reducing redundancies and superfluous operations to an absolute minimum. At the same time, consideration had to be given to the fact that the only peripheral equipment available with the PDP-8 were one magnetic tape transport, a high-speed punched paper tape reader, and a teletypewriter with low-speed paper tape punch. The result of these efforts was a two-step program that would not overload the system.

The first step consists of reading a block of data from the E/D magnetic tape and determining the amplitude and mass scale location of each spectral peak. These data, together with date and time are stored on punched paper tape. The second step of the program make use of the punched paper tape, from the first step, and the A/O magnetic tape. A block of data is read from the punched paper tape and data for the corresponding time interval are read from the A/O tape. Adjustments for attitude, velocity and orientation are combined into one correction factor which is printed, along with corrected and uncorrected concentrations and mass numbers, altitude, geographical location, date, and time, by the teletypewriter. This typewritten listing (See Figure 1) is the final output of the data processing program. A detailed description of this computer program is given in Appendix I.

The spectral peak models were obtained from analog output data taken from the spectrometer during laboratory calibration. The computer program not only determines the actual amplitude of single peaks but also resolves a multiple spectral peak into its component peaks and determines the actual amplitude of each peak. The existence of spectrometer saturation on any spectral peak, offset of the baseline and the average noise level during each sweep of the spectrometer are also indicated. An interpolation of A/O data is performed also to increase the accuracy of the final output data.

III Work Performed

The initial work on this grant was devoted to the manual extraction of Experiment Data from the E/D magnetic tapes through the use of strip charts. After considerable effort (as described in II) it was concluded that accurate, consistent amplitude readings of the spectral peaks could not be obtained using manual methods and that computer techniques were required to perform the iteration procedures necessary to reconstruct a spectral peak from a given set of commutated data points, especially where multiple overlapping peaks are encountered.

Following a detailed examination of previously prepared data processing software and of the capacity of our PDP-8 computer and its peripheral equipment, and a complete review of the output requirements from any data processing system for OGO-IV, Experiment 15, it was concluded that our PDP-8 system could be used to achieve the goals established for completion of work on this grant. The software for a data processing program was prepared (See Appendix I) and check-out procedures were initiated. A block of data from an E/D tape was run several times and compared qualitatively with a strip chart display of the same data. Some program errors were found and corrected however the output was not as consistent as it should have been. After considerable trouble-shooting work, it was decided that some intermittency was occurring within the interface electronics between the computer and the magnetic tape transport. Since insufficient funds were available to engage maintenance personnel, we attempted to locate the difficulties ourselves, and to make the necessary repairs. After many hours, most of it outside regular working hours, the trouble areas were gradually eliminated. What is believed to be the final repair was made very recently, thereby permitting the software check-out to be complete. Unfortunately, by this time the time limit of the grant had expired and all funds had been expended, therefore work on the four areas of interest originally proposed could not be conducted. While we did not accomplish our predetermined goals, it is most gratifying to have the necessary software to process experiment data on our own computer which is cost free except for maintenance and supplies which should be quite modest in the future because of the complete inspection conducted during the past several months.

In the process of developing the experiment data processing program, it became apparent that all possible orientations of the Orbital Plane Experiment Package (OPEP), in which the mass spectrometer was mounted, relative to the spacecraft could not be included, at each possible orientation of the spacecraft with respect to the flight velocity vector, and still keep the program within the capacity of the PDP-8 computer. Therefore a separate study was initiated to examine the influence of particles emitted from the various surfaces of the spacecraft upon the composition of neutral particles in the ion source for each possible configuration. A report [1], describing the theoretical development of an appropriate model to formulate this problem and convert the observed measurements to ambient concentrations by taking into account the influence of the spacecraft upon the measurements, was prepared and submitted to the sponsor. A set of equations were derived to account for all possible paths by which a particle could enter the ion source, including paths where a particle arrives at and is re-emitted from a number of surfaces, i.e., multiple bounces are included.

This work was then extended to include the actual calculations for OGO-IV, Experiment 15. A computer program was written for our PDP-8 and run while the computer-tape transport interface electronics were being repaired. For OGO-IV, Experiment 15 the greatest perturbation was introduced by the solar paddles and was found to be approximately one percent of the measured densities. A report [2] presenting these results is in preparation. It should be noted that these perturbations are introduced by ambient neutral particles, or neutralized ambient positive ions, which impinged on

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[1] "Theoretical Model for Conversion of Observed Neutral and Ion Densities to Ambient Densities for Orbiting Geophysical Observatories," Rpt. No. 03346-1-T, High Altitude Engineering Lab, Univ. of Michigan, Jan. 1970.

[2] "Perturbations to Ambient Neutral Particle Densities Due to Presence of an Orbiting Geophysical Observatory," Rpt. No. 03346-2-T, B. B. Hinton and R. J. Leite, High Altitude Engineering Laboratory, University of Michigan, In preparation.

some surface of the spacecraft and are subsequently re-emitted in such a manner that they arrived at the ion source directly or after traveling to other surfaces prior to their arrival at the ion source. Particles which are outgassed or leak from the spacecraft are not included in the above computation. If the locations and flux rates of the outgassing and leakage sources were known a similar calculation could be performed.

Nimbus IV was launched on April 8, 1970. Upon activation of the Filter Wedge Spectrometer during the fifth revolution it was found that the 1.2 to 2.4 micron band was degraded and the 3.2 to 6.4 micron band was totally obscured. Due to the existence of what appeared to be ice absorption bands in the shorter wavelength region and the occurrence of icing during ground testing, it was concluded the failure was due to ice forming on the detector. A committee was formed at Goddard Space Flight Center to investigate the failure and make recommendations to avoid future failures. We were asked by committee members and their colleagues to provide all available information concerning our measurements[3] of water vapor concentrations on OGO-II and IV since these data appear to be the only historical account of the outgassing of a spacecraft. The fact that both spectrometers had "open" ion sources and swept over the entire 0-50 amu band on each sweep make these data unique and the only actual outgassing flight data.

In view of this recent interest in water vapor concentrations in the aureole of spacecraft and the fact that people may be finally convinced that flight experiments, as they become more sophisticated, will be influenced by the materials being liberated from the spacecraft, the data from Reference 3 was reviewed to determine if a better understanding of the nature of the

[3] "Comparison of Water Vapor Measurements from Two Similar Spacecraft," B. B. Hinton, R. J. Leite, C. J. Mason; Trans. American Geophysical Union, Vol. 50, No. 4, p. 267 April 1969.

outgassing process could be obtained. The results of this review indicated that more information could be obtained, hence a more detailed treatment of the data was made. This material is being assembled and will be reported[4] in the near future.

IV Recommendations

In Section II a detailed description of the difficulties encountered in attempting to perform manual data processing and the impossibility of obtaining reliable data when using such techniques. Because of the delay in recognizing the futility of manual data processing, coupled with the time required to prepare and check the data processing program for the PDP-8 computer and time required to complete the hardware repairs, none of the investigations proposed for this grant were performed. It was not possible to process sufficient reliable data to perform any one of the four proposed studies.

In view of the fact that the data processing program is complete and the computer hardware repairs have been made, a strong recommendation is made that work continue by completing the four previously proposed investigations. It should be noted that the costs of using the PDP-8 computer are absolutely minimal. They consist of the costs for maintenance and the usual supplies required for data processing activities.

The four previously proposed investigations are as follows:

1. Atomic oxygen concentrations acquired during selected orbits from the first three months of flight of OGO-IV will be used to conduct the following studies:

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4. "Half-Life Determinations of Water Vapor Outgassing from OGO II and IV" C. J. Mason, Rept. No. 03346-3-T, High Altitude Engineering Laboratory, University of Michigan, in preparation.

a) Compare experimental data with the predictions of the CIRA 1965 model atmosphere for each location at which data was taken.

b) Make the same comparison using the U. S. Standard Atmosphere (1966).

c) Deduce an "experimental" exospheric temperature from the composition data.

The analysis programs for conducting these studies are nearly complete. These studies should provide a reasonably complete picture of the morning-evening variation of the neutral atmosphere, the response time characteristics of neutral density variations accompanying changes in the solar 19 cm radio flux, and magnetic range indices. Ultimately, these results will be correlated with the storm-indiced response of the ionosphere from Task 2 below.

2. During September 1967, two solar storms resulted in relatively large ionospheric disturbances. Observations of an accompanying red-arc were reported during one storm but not during the other. Both events were marked by large enhancements in the nighttime concentrations of H_e^+ and O^+. Data taken during each disturbance will be examined in an attempt to resolve the following questions:

a) Does the existence of an observable red-arc imply a different ionospheric composition and structure during the disturbed period?

b) What is the mechanism by which energy is injected into the ionosphere and is it the same with and without a red-arc?

c) What is the mechanism that results in the apparent southward drift of the enhanced regions of the ionosphere?

d) Is there a characteristic ionospheric response time associated with the build-up and decay of such disturbances?

3. Correlate the flight data with ground-based data from each of the five Thomson backscatter stations over which simultaneous measurements made. Comparison of these ion composition data will be used for the following studies:

a) Evaluation of plasma sheath effects upon the positive ion density measurements.

b) When two or more ground stations are encountered during the same orbit, use the horizontal ion distribution data between stations to supplement the vertical profiles obtained by the ground stations.

c) Attempt to resolve measurement anomalies experienced by several ground stations during past operations by correlation with flight data.

4. Attempt to establish the identity of positive ions having an apparent mass-to-charge ratio of eight and explain the production/loss mechanism of these ions. A theoretical model of suitable reactions has been formulated. A successful search of flight data for predicted distributions of constituents would permit identification of these ions and contribute to a better understanding of atmospheric structure.

In addition to the above investigations the following pertinent studies are highly recommended.

5. Recently Dr. W. B. Hanson indicated that interesting phenomena appear to be associated with the heavier ions (28^+-32^+ amu) in the vicinity of perigee, however, his instrument on OGO-VI has insufficient resolution to determine the required distributions. Analysis of these data would not only provide the necessary distribution relationships to permit a study of the phenomena but also would provide data from an earlier time period so that possible cyclic behaviors might be observed.

6. The failure of the Filter Wedge Spectrometer on Nimbus IV and the possible implication that the projected capabilities of the ERTS program may be seriously affected, has greatly increased the need for information pertaining to the outgassing and leakage of materials from spacecraft and the nature and composition of the aureole enveloping the vehicle. We have examined the decay of the water vapor concentration as a function of orbital lifetime for the first six months of operation of OGO-IV (See Ref. 3). It is recommended that this study be extended to include the remaining period of operation of OGO-IV Experiment 15. In addition, a review of all neutral particle data should be conducted to determine whether any other data related to outgassing phenomena may be present. It should be emphasized that this experiment is the only source of information available in which contamination data were accepted along with the atmospheric composition data and which examined the entire mass range by sweeping between 0 and 50 amu. To date it is the only spectrometer that has demonstrated it is capable to perform both neutral particle and positive ion measurements.

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ORBIT+    768    DATE+   9+  18+  67

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 +17.1 +0.0000000E+00 +0.9911285E+19 +0.0000000E+00     "
 +15.7 +0.0000000E+00 +0.8360079E+19 +0.0000000E+00     "
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MODE     OFFSET              NOISE  DGEM=0010
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 +27.5 +0.0000000E+00 +0.7857986E+19 +0.0000000E+00
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 +  4.3 +0.3879994E-14 +0.1654237E+21 +0.6116516E+06
 +  3.2 +0.1779997E-14 +0.2212719E+20 +0.3753364E+05


ORBIT+    768    DATE+   9+  18+  67

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 +  7.9 +0.2979995E-14 +0.7753247E+16 +0.2310466E+02
 +  1.3 +0.1999998E-14 +0.7766473E+16 +0.1553294E+02
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FIGURE 1: Output from Data Processing Computer Program.

APPENDIX I

DATA PROCESSING COMPUTER PROGRAM FOR OGO-IV EXPERIMENT 15

This program was prepared for use on a Digital Equipment Corporation PDP-8 computer having a 4000 word memory, an Ampex TM-9 magnetic tape transport, a Digitronics high speed punched paper tape reader, and a teletypewriter with low speed paper tape punch. It is divided into two parts: Phase I where data are extracted from the Experiment Data (E/D) magnetic tape, identified and adjusted using calibration and instrument factors, and stored on punched paper tape; and Phase II where these data are adjusted for attitude and spacecraft influence factors, using the punched paper tape from Phase I and the Attitude-Orbit (A/O) magnetic tape, and printed, with appropriate headings, by the teletypewriter or stored on punched paper tape for additional analysis or transfer to magnetic tape.

An E/D tape contains three information channels; (XI) a direct spectrometer output, (X10) a direct spectrometer output multiplied by ten, and MON a mass ramp scale and instrument housekeeping output. The cyclic operation of the spectrometer causes the two modes of operation (neutral particle and positive ion) to be placed serially on the E/D tape, even numbered modes being neutral particle data and odd numbered modes being positive ion data. Within each mode, the spectrometer is sequentially switched between a spectral density distribution output and a type of cummulative density distribution output. In the present discussion we are concerned only with the spectral density distributions, namely, modes 1, 3, and 5 for positive ions and modes 8, 10, and 12 for neutral particles. Modes 7 and 14 are the data link calibrate modes in which three known voltages are recorded. Within each of these mode steps the spectrometer sweeps from 50 to 0 atomic mass units (amu). Two nearly linear ramp segments are used. The initial ramp extends from 50 amu to approximately 10 amu where the slope of the ramp changes to approximately one-half its original value.

Data processing is initiated by mounting the appropriate E/D tape and inserting the file and record numbers, associated with the beginning of the desired data, through the teletypewriter. The tape transport will advance to the proper location on the E/D tape, read a block of data, and commence processing. As these data are read, parity error checks are made; if parity errors occur within any record of data, that record is automatically skipped.

Phase I

After the correct position is reached, a portion of this next record is read in. Due to storage limitations, a complete record from an E/D tape cannot be placed in the memory core at one time, so only the information associated with the XI channel is read in first. From past experience, it has been found that this channel has the most error free information in the calibrate step (modes 7 and 14) and thus they are used to find the beginning of the sweep in the monitor channel.

When a calibrate step is found, the program reads in the monitor channel information corresponding to the next sweep having output data. The beginning of the sweep is then located. A third order equation is fitted to the monitor sweep down to the point at which the sweep changes slope and a straight line portion is fitted to the tail end of the sweep. Then the point at which the sweep goes to zero is estimated, and the point at which the two sweeps meet is calculated. These curves provide the means to calculate the voltage in the ramp voltage to amu conversion later in the program. They also provide the end point of the sweep and essentially the slopes of the ramp voltage-mass equation.

The program then rereads the data associated with the XI channel and determines a noise threshold for that sweep. This is to eliminate any spurious peaks from being considered as masses. In addition, to distinguish spectral peaks from noise spikes, each peak must contain at least three data points. A preliminary scan of the data is made to separate any spectral peaks evidencing voltage saturation. If there are saturated peaks, the mass number is noted and the peak is discarded. Then the data are rescanned for all unsaturated peaks, having at least three data points above the noise threshold. A mathematical model is fitted to the peak and the square of the differences between this model and the peak are calculated. The model is translated in both the peak height and time scale directions until the sum of the squares of the differences between the model and the original peak is minimized.

The position of the peak on the time scale is used to determine the ramp voltage on the MON channel which in turn determines the mass value of the constituent. The amplitude and mass location of the spectral peak are punched on paper tape along with date and time data to permit location of corresponding information on the A/O tape. This is the output from Phase I.

Each peak encountered is treated in this manner until the end of the sweep is reached. Then the X10 channel is processed using the same MON channel data.

If parity errors are encountered or the beginning of a sweep cannot be found, the program goes back to searching for the next mode 7 or 14 data and continues the Phase I data processing.

Currently, the program processes one file at a time and then halts. This is arbitrary and is done to restrict the amount of paper tape punched at one time.

Phase II

The second portion of the program starts by searching for the location on the A/O tape corresponding to the data and time from the Phase I output. An interpolation is made to determine the exact time since A/O data is provided only on every whole minute. The local time and velocity vector are computed and printed along with the orbit number, date, GMT, noise, peak amplitude and mass value. In addition, the existence of A/O tape errors and operation of the cold gas jets and OPEP drive motors on the spacecraft are also indicated.

These data form the output from Phase II, which corresponds to the final data processing output. They can be presented as teletypewriter output or punched paper tape output at the option of the user.